AN EVALUATION OF THE TIME CONSTRAINED AND RESOURCE CONSTRAINED SCHEDULING FEATURES OF COMMERCIALLY AVAILABLE PROJECT MANAGEMENT SOFTWARE

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ABSTRACT

An Evaluation of the Time Constrained and Resource Constrained Scheduling Features of Commercially Available Project Management Software

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The major suppliers of commercially available project management software were identified. These suppliers were surveyed to ascertain the nature of the time constrained and resource constrained scheduling effectiveness provided by the software. The survey also identifies the major features of the software as well as the minimum and recommended computer hardware requirements for the software. The software suppliers were all provided with the same sample network for time constrained and resource constrained scheduling. The results of the scheduling calculations are analyzed to evaluate the effectiveness of the software's procedures. No specific recommendations or opinions are given concerning any of the individual software products or suppliers.

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1. INTRODUCTION

1.1 Purpose

It is the intention of this thesis to analyze the performance of the time and resource constrained resource scheduling procedures of commercially available project management scheduling software. There are currently available a multitude of software products which are intended for the use of all types of project managers, not just those in the construction industry. Many of these software products focus on only one of the many aspects of a project manager's concerns.

In general, project management software can be classified into four general categories: accounting, communication, scheduling, and multifaceted software products. The accounting type of software products are designed to track cost and resource expenditures on each of the individual tasks which make up the overall project. These products provide for the planning of resource utilization and a detailed history of where resources have been expended. They also usually provide a comparison with a selected base line, typically the project budget. This provides the project manager with a picture of which tasks or activities are exceeding the anticipated costs. From this

information, project managers can focus their attention on the activities which, historically, have resulted in cost over runs.

A second general category of project management software products, the communication or graphics type, are designed as a communication tool. These products allow the project manager to graphically represent the status of each task or activity. With these graphic representations, the project manager can more easily communicate to superiors, subordinates, and colleagues, the status of each activity, past performance, and expected future outcomes. These software projects do not actually schedule the activities of a project. They depend on information provided by either the manager or another software product to show the relationships between activities, scheduled dates, percent complete, etc.. As such, these products are typically supplied as add-ons, or companion products to scheduling software products.

What is typically called scheduling software is the third general category of project management software products. These products allow the project manager to schedule activities within given constraints. The constraints can be either external, such as required phase and contract completion dates, or internal, such as one activity may not begin until another activity is complete. External constraints can be considered those restrictions placed on a project from outside the project management organization or the project itself. One

typical example of an external constraint would be a required delivery date or contract completion date. Internal constraints are considered to be those imposed by the project manager for business reasons or as a result of professional judgment. Examples of these types of constraints are how many people to assign to a particular task, or the order in which to accomplish tasks.

Software products which fall into the fourth general category provide a combination of at least two of the previous three categories. As such, these products can be termed multifaceted project management software.

The ability to automatically level out peaks and valleys in the required daily amounts of resources is one major feature of scheduling software, and the multifaceted products which incorporate scheduling software features. This procedure is typically referred to as “leveling,” “smoothing,” or “time constrained resource scheduling.” A second major feature of scheduling software is the ability to schedule activities based on the maximum available amounts of a given resource or resources. This procedure is referred to as resource “allocation,” or “resource constrained scheduling.” To confuse the issue, resource constrained scheduling is also often referred to as “leveling.”

The procedures and computer algorithms which are used to perform the time and resource constrained scheduling procedures can be very effective. However, these procedures have several draw backs. First, they are inherently

inflexible and sequential in nature. Secondly, they rely on the expertise of the code writer and project manager to make logical decisions. Given this, these products may not always provide the optimal solution. Project management software products compensate for these shortcomings with the rapid results provided by the speed of modern desktop computers. A good discussion of the limitations of scheduling software is provided by Mr. Levine in his two article series for *PMNETwork* (Levine 1994a and 1994b).

This thesis will evaluate the effectiveness of the time and resource constrained resource scheduling procedures of various scheduling software products by comparing their results with a manually calculated optimal solution. The optimal solutions are developed from a short sample network of 26 activities with one resource, mandays, assigned to each activity. The network was designed to be simple enough for manual calculation of time and resource constrained resource scheduling and yet large enough to demonstrate the differences between software products.

1.2 Scope

In order to accomplish its purpose, this thesis first identified as many commercially available computer scheduling software products as possible.

The vendors of these products were then asked to respond to a short survey on the characteristics and requirements of their product. In addition, the survey respondents were asked to enter the sample network of tasks into their product. The respondents were also asked to perform a time constrained resource scheduling calculation on the sample network as well as a resource constrained resource calculation. The various results of the calculations were grouped into two separate sample populations. These sample populations were then compared to the optimal solutions calculated manually.

2. BACKGROUND

2.1 Scheduling Methods

It is not the purpose of this thesis to discuss at any length the various scheduling methods. It is considered necessary, however, to briefly review the most common methods and terminology. An excellent reference for a comprehensive discussion of scheduling methods and procedures is Moder et al. (1983).

The most basic method of scheduling the various activities of any given project is bar charting. This is also commonly referred to as a Gantt chart. A Gantt chart is a graphic representation of the duration of each activity. A horizontal bar is placed for each activity in the overall project such that its width represents the activity's overall duration. The relative placement of the bars right or left indicates the anticipated start and finish dates. The principal draw back with Gantt charts is that they do not depict the relationships and dependencies between activities. In spite of this, Gantt charts are commonly used as a simple graphical tool in communicating project status. Almost all scheduling software programs include Gantt charts as a basic form of output. As will be discussed later, Appendices B, D, and F are typical bar, or Gantt charts.

The next most common method of project scheduling is referred to as the Critical Path Method (CPM). CPM can actually be divided into two major subcategories. The first being activity on arrow, or simply the arrow diagramming method (ADM). With ADM each activity is represented by an arrow. The duration of each activity is centered just beneath the arrow. Activity arrows are connected at nodes which represent the dependencies or relationships between activities. Activity on node or the precedence diagramming method (PDM) is the second sub-category. PDM is almost the exact opposite of ADM in the way that activities are represented. In PDM, each activity is represented by a node, typically in the form of a box which contains all information relevant to the scheduling of an activity. The relationship between activities is depicted with arrows which lead from predecessors to successors. Both of these CPM methods solve the basic problem with bar charts in that they accurately represent the relationships between activities.

The principal advantage of CPM techniques is the ability to perform the scheduling calculations which are commonly referred to as forward and backward passes. The forward pass calculation develops the early start of each activity from the finish of preceding activities. The process begins with any activities which have no predecessors. The earliest possible start of any

successor activities is calculated from the latest finish of all its predecessors plus any lag or additional delay required. Conversely, on the backward pass, the late finish and consequently the late start of each activity can be calculated by starting from the activities with no successors. The late finish of all activities with no successors is typically set at either the early finish of the latest activity, or the required completion date. The late finish of any predecessor is then determined from the earliest late start of all its successors minus any lag or required delay. The backward pass can also provide the amount of total and free float for each activity. The activity's free float is defined as the amount of time which an activity can be delayed with out delaying the early start of any succeeding activity. Similarly, the total float of an activity is the amount of time which the activity can be delayed without delaying the early finish of the entire project. The series of activities with the least total float is commonly referred to as the critical path, hence the name for these scheduling methods. CPM in either or both of its forms is the basis for the vast majority of currently available scheduling software.

A third scheduling method called PERT, for Performance Evaluation and Review Technique, is less commonly used. The principal feature of PERT is the incorporation of multiple possible durations and the associated probability of each duration with either arrow or precedence diagramming.

Using PERT a project's total duration can be calculated as well as the probability of actually meeting the projected date. PERT has proved useful in research and development projects as well as other areas involving new or untried technology and techniques. The applicability and effectiveness of PERT is inversely related to the degree of certainty in the duration of the activities which compose a project. One final note on PERT is that the term is often used incorrectly to describe the precedence diagramming method.

In researching this thesis a wide variety of new scheduling techniques were encountered. Several of these techniques deserve mention. Russell and Wong (1993) and Russell and Caselton (1988) describe a scheduling method and software product developed for projects which involve a significant repetition of a series of activities. Moselhi (1993) describes how the direct stiffness method of structural analysis can be applied to scheduling projects. This technique is applicable to projects with scheduling constraints, and the analysis of time - cost trade-offs. Badiru (1993) presents a variation on CPM in which resources replace activities as the principal building block of a schedule.

2.2 Time Constrained Resource Scheduling

Time constrained resource scheduling is one of the two basic resource scheduling procedures performed by the majority of scheduling software. Unfortunately, the majority of research and papers have been devoted to resource constrained resource scheduling, the other basic resource scheduling procedure (Seibert and Evans 1991). Resource constrained resource scheduling will be discussed in the next section.

The starting point for time constrained resource scheduling is a CPM network of a project for which the forward and backward passes have been completed. Each activity is then assigned its required resources based on unlimited availability of the required resources. Each activity can then be moved or slid within its available free and total float in order to minimize the changes in required resource levels between time periods. The process is carried out for each non-critical activity in the project for the simple reason that the critical activities have no float. Any change in the scheduling of a critical activity would either violate the relationships between the activities or delay the early finish of the project. In time constrained resource scheduling there are no set limits on the amount of resources available. The only hard

criteria is that the fixed completion of the last activity not be delayed. As mentioned in section 2.1 above, the fixed completion can be either the early finish of the overall project as calculated by the forward pass, or an imposed date such as the required project completion. Time constrained resource scheduling is considered necessary as fluctuations in resource levels "are very undesirable because they often present labor, utilization, and financial difficulties to the contractor." (Easa 1989)

The methods of time constrained resource scheduling can generally be categorized as either heuristic or optimization. The heuristic approach uses the application of various rules of precedence to decide which of several activities will be scheduled first and which will be postponed when an undesirable change in resource requirements occurs. An optimization approach on the other hand examines all possible scheduling scenarios and then chooses the best solution based on a given measure or metric.

The principle advantage to a heuristic approach is that significantly less calculation time is required. Conversely, the principle disadvantage of an optimization approach is that each possible scheduling scenario must be evaluated. The number of calculations required and the associated time for this approach typically limits its applicability to desktop computers, even for short

simple networks. For this reason, the majority of scheduling software products utilize a heuristic approach to time constrained resource scheduling.

The principle disadvantage to a heuristic approach can best be described as the approximate nature of the result. A heuristic method, by its very nature will not necessarily find the one best solution. Rather, it uses the application of various rules to decide which activities should be scheduled and which should be postponed. The choice of priorities in scheduling activities can significantly affect the outcome. On the other hand, the optimization approach can choose which scenario provides the “best” solution by evaluating each and every scheduling scenario.

There are two common metrics used for evaluating the effectiveness of time constrained resource scheduling procedures. The first metric is the sum of the absolute values of the changes in resource requirements between time periods. The second metric being the sum of the squares of the changes in resource requirements per time period. Either metric provides a measure of the effectiveness of the procedure at reducing the variation in resource requirements per time period for a particular project or network. It must be pointed out that neither metric can be used to compare time constrained resource scheduling results between projects. The metrics are only useful in comparing the results of a scheduling procedure with the original CPM

network or baseline. The unique characteristics of each individual network such as number of activities, amount of float, and percentage of critical activities precludes comparisons between networks. The squaring metric does provide an advantage in the exaggeration of small differences in time constrained resource scheduling performance. For this reason, the squaring metric was chosen in evaluating the effectiveness of the time constrained resource scheduling procedures used in this thesis.

2.3 Resource Constrained Resource Scheduling

The second basic resource scheduling procedure, which is conducted by scheduling software, is known by a variety of terms. The most commonly used terms are resource allocation, resource constrained scheduling (Drexl and Gruenewald 1993) and (Oguz and Bala 1994), and unfortunately, resource leveling (Primavera 1991). As with the procedure for time constrained resource scheduling discussed above, resource constrained resource scheduling begins with a resource loaded CPM diagram with the relevant calculations of early and late, start and finish, and free and total float completed. For resource constrained resource scheduling the early finish of the last activity is not fixed or locked. Rather the total amount of a resource or resources available is

given a set maximum amount available per time period. Hence the terminology, resource constrained resource scheduling. The maximum available limit of a resource may be constant over the duration of a project, or in some cases, variable with time. The limits imposed may be the result of actual resource availability or management decisions. Once the resource limits are set the project is rescheduled one activity at a time. When there are insufficient available resources to accomplish a given activity it must be postponed until the resources are available. There are two basic variations on these rules which should be considered. The first allows for an activities total duration to be adjusted without changing the total required resources to complete the activity. This is commonly referred to as effort driven scheduling. The name derives from the fact that the anticipated effort and available resources determines an activities duration. The second variation is to allow activities to be temporarily suspended or interrupted to accommodate resource requirements in other, more critical activities. This is commonly referred to as splitting an activity. Some software products allow splits as an option when performing scheduling.

Resource constrained resource scheduling methods can also be classified into the same two general categories of heuristic and optimization methods discussed for time constrained resource scheduling. The heuristic

method follows preset rules and priorities to determine the order in which activities are rescheduled. The optimization method examines all possible scheduling scenarios and then chooses the best solution.

Similar advantages and disadvantages apply for resource constrained resource scheduling as do for time constrained resource scheduling. Optimization is calculation and memory intensive while the heuristic approach offers only an approximate solution. Oguz and Bala (1994) provide a good description of just how calculation intensive the optimization method is. The majority of scheduling software uses the heuristic method due to the limitations of desktop computers.

One point which must be stressed for the heuristic method of resource constrained resource scheduling is that the order, or priority, in which activities are rescheduled can significantly affect the outcome. For example, the election to schedule a non-critical and resource intensive activity ahead of a critical activity may significantly delay the early finish of the last activity.

For either the heuristic or optimization method of resource constrained resource scheduling the typical metric of performance is the overall delay in the completion of the project as compared to the unconstrained early completion. A shorter scheduling delay being preferred over a longer one due to the relatively high daily overhead costs associated with most projects. The analysis

in this thesis uses the metric of the overall delay in the project expressed as a percentage of the original duration. The one drawback to this metric is, again, that the results can not be compared between two different networks. This is even true when the overall delay in completion is expressed as a percentage of the original duration. The reasons for this lack of comparability are the same as for time constrained resource scheduling.

The literature on resource constrained resource scheduling is much more plentiful and varied than that for time constrained resource scheduling. This is probably a direct result of the much more troublesome problem of not having enough resources as compared to the somewhat idealistic problem of minimizing variations in resource requirements. Moder et al. (1983) provide an excellent and thorough discussion of the theory and methodology of resource constrained resource scheduling. Shanmuganayagam (1989), and Drexl and Gruenewald (1993) provide some innovative approaches to the mathematical aspects of resource constrained resource scheduling using optimization methods. Finally, Russell and Caselton (1988) discuss the application of resource constrained resource scheduling to projects with a highly repetitive series of activities.

3. RESEARCH METHODOLOGY

3.1 Data Gathering

The process of gathering data for this thesis involved four steps or phases. The first being the identification of as many vendors of scheduling software as possible. A literature search of previous surveys and reviews of construction software resulted in four excellent sources of information. Badiru and Whitehouse (1989), *Constructor* (1992), and PMNETwork (1994a and 1994b) all provided extensive and comprehensive lists of software vendors. These four lists were consolidated into a database of potential contacts. Those software products which were clearly not within the scope of this thesis were excluded. Duplicate vendor addresses or points of contact were retained as separate records in the database to ensure that every vendor could be contacted.

A survey of the basic requirements and features of typical scheduling software was developed next. The survey covered the basic categories of: vendor information, operating system requirements, software features, software output, time analysis, resource characteristics, and resource analysis. In addition, the survey included a simple 26 activity network loaded with a single resource, mandays. All of the relationships between the activities are

finish to start. This network was intentionally kept relatively simple to allow for manual time and resource constrained resource scheduling and to increase the chances of vendors actually responding to the survey.

An essential part of the survey is the request that each vendor load the sample network into their software product. Each vendor is asked to provide a baseline tabular report of the network and a resource histogram, if possible. The baseline reports as well as any other information provided are to be used as a control to ensure that the network was entered into the software correctly. After completing the baseline reports, the vendors are asked to perform separate time constrained and resource constrained resource scheduling calculations on the baseline network. For the time constrained calculations, it is emphasized that the early finish of the last activity can not be delayed. For the resource constrained calculations the total maximum daily resource availability is set at ten men per day. This limit was intentionally set just slightly below the peak baseline requirement of twelve men per day. A copy of the survey is attached as Appendix A. The individual results will be discussed in detail later in Section 5.

Once the survey was developed each potential vendor was contacted by telephone to request their participation in the survey. The original database

included over one hundred and fifty vendors, many being duplicate vendor names with various addresses, phone numbers and points of contact.

Due to the rapid rate of change in the software industry many vendors were unable to be contacted. Almost universally, either the phone number was disconnected, had been changed, or the point of contact no longer worked for the company. In one particular case, the company was in receivership and their lawyers answered the call. In total, seventy one vendors were able to be contacted. At this point in the research, duplicate vendor addresses and multiple vendors of the same software product were eliminated.

Of the vendors contacted, twenty one were no longer selling a scheduling product or the product did not perform resource analysis. Only one vendor declined to participate in the survey over the telephone. The remaining fifty vendors were considered valid for the purpose of the survey and this thesis. Each vendor was sent a copy of the survey with a cover letter addressed to the point of contact. The cover letter repeated the request for their participation and detailed the scope and purpose of this thesis. A list of the valid vendors with their mailing addresses, points of contact, telephone and facsimile numbers is attached as Appendix H.

The next phase in the data gathering process was to encourage the vendors to respond to the survey. Although all of the vendors were very

helpful over the phone, they were less than enthusiastic in replying to the survey. During follow-up telephone calls it became apparent that some of the products originally considered valid were in fact accounting or graphics type software. Several vendors eventually declined to participate based on a lack of time to respond. This reduced the sample population to a total of thirty one. Eventually only fourteen vendors responded to the survey.

3.2 Methods of Analysis

The analysis of the data provided by the survey respondents was straight forward, but time consuming. The vendors responses to the first half of the survey were entered into a database for reference purposes. This database is attached as Appendix I.

The vendor's responses to the second half of the survey were each analyzed in detail. All three of the data sets (unconstrained baseline, time constrained calculations, and resource constrained calculations) provided by the vendors were analyzed. The unconstrained baseline provided was evaluated as a control to ensure that the sample project had been entered properly. In addition, the time constrained and resource constrained

calculations were also analyzed to ensure that the network logic was not violated during scheduling.

For the time constrained calculations, the daily resource requirement was extracted from either the tabular reports, Gantt charts, or the resource histogram provided. The daily resource requirement for each response was entered into a computer spreadsheet. The spreadsheet was then used to calculate the sum of the squares of the difference in required resources from one day to the next for each respondent. The resultant was used as a metric of the effectiveness of the calculation procedures and computer algorithms of the software product.

For the resource constrained calculations, the unconstrained baseline duration of fifty one days was subtracted from the total duration of the project after running the resource constrained resource scheduling. The difference was divided by the baseline duration of fifty one and multiplied by one hundred. The resultant was an expression of the percent delay caused by the resource constrained calculation algorithms of each software product.

The vendor responses for the time constrained and resource constrained calculations were then separated into two separate groups or sample populations. One group for time constrained and the other for resource

constrained. Each group was then compared to the optimal time constrained and resource constrained solutions developed manually by the author.

Due to the highly competitive nature of the software industry, and for liability reasons, the individual results of the time and resource constrained calculations for each vendor are not identified by name in this thesis. In addition, no recommendations or endorsements of any individual products can be made.

4. PRESENTATION OF DATA

4.1 Baseline Solution

The baseline solution was developed manually using a computer spreadsheet. Using the same sample network contained in the survey a baseline or unconstrained network was developed. Each activity was scheduled in accordance with the predecessor and successor logic provided in the survey. A forward pass calculation was then performed. The forward pass provided each activity with both its early start and early finish. A backward pass was then executed to obtain each activities late finish and late start. A second backward pass provided the total and free float for each activity. Table 1 presents the results of these calculations. The total duration of the baseline project is fifty one project work days. When the resource constrained metric of the sum of squares of the daily differences in resource requirements is calculated for the baseline schedule the result is 249. This metric was calculated for the baseline as a standard by which to measure the effectiveness resource constrained scheduling procedures. A bar chart of the baseline schedule is attached in Appendix B. A resource histogram of the baseline schedule is attached as Appendix C.

Table 1: Results of Baseline Calculations

Activity ID	Descrip.	Dur.	Men / Day	Early Start	Late Start	Early Fin.	Late Fin.	Float Tot.	Float Free
30	C	1	4	1	2	2	3	1	0
10	A	5	3	1	1	6	6	0	0
90	I	2	3	2	3	4	5	1	0
40	D	4	2	2	10	6	14	8	6
100	J	5	4	4	5	9	10	1	0
20	B	1	5	6	6	7	7	0	0
50	E	5	3	7	9	12	14	2	0
80	H	10	5	7	7	17	17	0	0
110	K	6	2	9	10	15	16	1	0
60	F	2	4	12	14	14	16	2	1
140	N	4	2	15	16	19	20	1	0
120	L	5	3	15	16	20	21	1	0
70	G	12	2	17	17	29	29	0	0
150	O	5	3	19	20	24	25	1	0
130	M	8	5	20	21	28	29	1	0
160	P	4	2	24	25	28	29	1	0
190	S	7	4	28	29	35	36	1	0
170	Q	3	4	29	29	32	32	0	0
180	R	4	2	32	32	36	36	0	0
230	W	10	4	35	38	45	48	3	2
200	T	4	3	36	36	40	40	0	0
210	U	5	5	40	42	45	47	2	2
220	V	7	2	40	40	47	47	0	0
250	Y	3	5	47	48	50	51	1	1
240	X	4	3	47	47	51	51	0	0
260	Z	1	4	51	51	52	52	0	0

Note: Early Start, Late Start, Early Finish, and Late Finish are indicated in project work days. Activities start or finish on the morning of the day indicated.

4.2 Time Constrained Solution

With the unconstrained baseline schedule established the resource constrained resource scheduling of the network was performed. To repeat the earlier discussion on time constrained resource scheduling, the principle constraint during this scheduling process was that the early finish of the last activity could not be delayed. That is activity 260 could not finish any later than the morning of the 52nd day. In addition, no splitting of activities or change in activity duration was considered. To insure that the early finish of activity 260 was not delayed, all activities with zero total float were scheduled first. This effectively removed them from the time constrained resource scheduling process. The activities with zero total float are: 10, 20, 70, 80, 170, 180, 200, 220, 240, and 260. These activities constitute the critical path for the project. Each of the remaining activities was initially scheduled on its original early start date from the baseline. The sum of the square of the difference in resource requirements from one day to the next was then examined beginning with the first day of the project. If the result of this metric was less than or equal to one on the day before the start of any activity, the activity was not considered for postponement. The first point at which the

metric is greater than one is between days 6 and 7. This coincides with the end of activity 20 and the beginning of activities 50 and 80. Since activities 20 has already been scheduled and 80 is critical they can not be considered for rescheduling. Activity 50, however, has two days of total float and can be delayed without delaying the overall project. In delaying the start of activity 50 by two days, the successor activities are also delayed and the metric is reduced to 209. The delay in scheduling the start of activity 50 effectively makes activity 50 and its successors with less than two days float critical. This includes activities 60, 140, 150, 160, and 190. Activity 230 still has one day each of free and total float. The next point at which the resource metric is greater than one and associated with a non-critical activity is between days fourteen and fifteen with the start of activity 120. When the start of activity 120 and all of its successors with no free float are delayed by one day the resource metric becomes 165. This change also causes activities 120, 150, and 160 to become critical. The last point at which the schedule can be adjusted under the given criteria is on day 40 with the start of activity 210. If activity 210 is delayed one day the resource metric jumps back up to 215. However, if activity 210 is delayed a second day, still within its float, the resource metric drops to 115. This is considered a significant improvement over the original metric value of 249.

Table 2 presents the time constrained resource scheduled project. It should be noted that the free and total float values for this schedule have a significantly different meaning from the baseline schedule. In this case, each activity with free or total float can be delayed without impacting the early completion of activity 260. If any activity is delayed, however, the time constrained scheduling of resource requirements can be significantly affected. For this reason, the concept of float is not applicable to a time constrained resource scheduled project. Appendix D is a bar chart of the project after the manual time-constrained resource scheduling. Appendix E is the daily resource histogram of the project after time constrained rescue scheduling.

Table 2: Results of Time Constrained Calculations

Activity ID	Descrip.	Dur.	Men / Day	Early Start	Late Start	Early Finish	Late Finish	Float Tot.	Float Free
30	C	1	4	1	2	2	3	1	0
10	A	5	3	1	1	6	6	0	0
90	I	2	3	2	3	4	5	1	0
40	D	4	2	2	10	6	14	8	8
100	J	5	4	4	5	9	10	1	0
20	B	1	5	6	6	7	7	0	0
50	E	5	3	7	9	12	14	2	0
80	H	10	5	7	7	17	17	0	0
110	K	6	2	9	10	15	16	1	0
60	F	2	4	12	14	14	16	2	1
140	N	4	2	15	16	19	20	1	0
120	L	5	3	15	16	20	21	1	0
70	G	12	2	17	17	29	29	0	0
150	O	5	3	19	20	24	25	1	0
130	M	8	5	20	21	28	29	1	0
160	P	4	2	24	25	28	29	1	0
190	S	7	4	28	29	35	36	1	0
170	Q	3	4	29	29	32	32	0	0
180	R	4	2	32	32	36	36	0	0
230	W	10	4	35	38	45	48	3	2
200	T	4	3	36	36	40	40	0	0
210	U	5	5	40	42	45	47	2	2
220	V	7	2	40	40	47	47	0	0
250	Y	3	5	47	48	50	51	1	1
240	X	4	3	47	47	51	51	0	0
260	Z	1	4	51	51	52	52	0	0

4.3 Resource Constrained Solution

The process of resource constrained scheduling was conducted next. To briefly repeat what was said in section 2.3, for resource constrained scheduling the principle constraint imposed is that the total requirement for a given resource can not exceed a set maximum amount. The intent being to anticipate and avoid any over commitment of available resources. As described in section 4.2 for time constrained scheduling, the process of resource constrained scheduling begins with the resource loaded baseline schedule of the project with forward and backward pass calculations completed.

The first actual step in the resource constrained scheduling process is to identify the priority order in which the activities will be considered for scheduling. The order in which activities are considered for scheduling is critical to the effectiveness of the procedure. For example, if an activity with available free float were to be scheduled first and then a lack of available resources delayed the start of a critical activity, the early finish of the project would be unnecessarily delayed. Therefore, priority in scheduling should be given to those activities which have the least schedule flexibility. The least

amount of schedule flexibility could also be termed the greatest potential for delaying the early finish of the overall project. For the manual resource constrained scheduling of the sample project, activities were sorted in ascending order of early start, amount of total float, and amount of free float. The primary sort, in order of early start, was chosen so that each activity was considered for scheduling as soon as the activities predecessors would allow. The secondary sort, in order of total float, was chosen so that the activities with the least flexibility in scheduling were considered first. Finally, the third sort criteria of free float further refines the selection for scheduling of activities with less schedule flexibility.

The resource requirement limit of a total of ten men per day for all activities was previously chosen for the sample network when developing the vendor survey. With the resource requirement limit imposed the final phase of the resource constrained scheduling process was begun. Each activity was initially considered for scheduling on its baseline early start date in priority order. If sufficient resources were available to begin the activity, it was scheduled for its complete duration. As with time constrained resource scheduling, no splitting or change in duration of activities was considered. If there were insufficient resources to begin an activity its start was delayed until sufficient resources were available. The start of any other lower priority

activities able to begin on the same day was also delayed. In addition, any successors to the delayed activity must also be delayed in order to preserve the network logic.

The first resource shortfall occurs on project day 7 with the commencement of activities 50 and 80. Activity 100 is already scheduled with a requirement for four men per day. Both activity 50 and 80 can not be scheduled due to a lack of available resources. Activity 50 is a lower priority and is therefore delayed due to its higher amount of float. The early start of activity 50 is postponed two days until resources are available. The delay in start of activity 50 causes a ripple effect through its successor activity 60 and other subsequent successors, 140, 150, 160, 190, 200, 210, 220, 230, 240, 250, and 260. Activities 70, 170, and 180 are not delayed at this point as there is sufficient float between them and their predecessors to absorb the two day delay. With the schedule thus partially recalculated, the next resource shortfall occurs on project day 14 with the potential start of activity 60 an then on project day 15 with activity 120. This procedure of checking available resources, delaying activities, and successors is carried out through the remainder of the schedule.

The final allocated schedule has a total duration of 56 days, or 9.8% longer than the baseline. Table 3 presents the results of the resource

constrained calculations. Appendix F is a bar chart of the resource constrained schedule. Appendix G is a resource histogram of the resource constrained schedule.

The concept of float can be applied to the resource constrained solution unlike the time constrained solution. However, when calculating float, resource availability must be considered as well as the late start of successors. Similar to the baseline calculations of float, the resource constrained float calculations are made with respect to the revised late finish of the last activity, 260. In addition the resource limit of ten men per day must also be taken into consideration when performing the float calculations. Specifically, an activity losses its float and can not be delayed if the delay would cause a lack of available resources for any successor. This effectively reduces the amount of float available to many activities, especially those which are resource intensive.

Table 3: Results of Resource Constrained Calculations

Activity ID	Descrip.	Dur.	Men / Day	Early Start	Late Start	Early Finish	Late Finish	Float Total	Float Free
30	C	1	4	1	1	2	2	0	0
10	A	5	3	1	4	6	9	3	0
90	I	2	3	2	2	4	4	0	0
40	D	4	2	2	5	6	9	3	0
100	J	5	4	4	4	9	9	0	0
20	B	1	5	6	8	7	9	3	0
50	E	5	3	9	10	14	15	1	1
80	H	10	5	7	11	17	21	4	0
110	K	6	2	9	9	15	15	0	0
60	F	2	4	15	15	17	17	0	0
140	N	4	2	17	17	21	21	0	0
120	L	5	3	17	17	22	22	0	0
70	G	12	2	17	21	29	34	4	0
150	O	5	3	21	21	26	26	0	0
130	M	8	5	22	22	30	30	0	0
160	P	4	2	26	26	30	30	0	0
190	S	7	4	30	30	37	37	0	0
170	Q	3	4	30	34	33	37	4	0
180	R	4	2	33	37	37	41	4	0
230	W	10	4	37	37	47	47	0	0
200	T	4	3	37	41	41	45	4	0
210	U	5	5	47	47	52	52	0	0
220	V	7	2	41	45	48	52	4	0
250	Y	3	5	48	53	51	56	5	5
240	X	4	3	52	52	56	56	0	0
260	Z	1	4	56	56	57	57	0	0

4.4 Summary of Responses

A total of 50 vendors were still considered valid after the initial telephone contact. During follow up telephone calls it became apparent that 14 of the software products were in fact of the accounting or graphics type and did not in fact perform resource scheduling. In addition, five vendors eventually declined to participate based on being too busy to respond to the survey and run the project through their product. Of the remaining 31 vendors only 14 eventually responded to the survey. The network for five of the products was entered by the author into either demonstration versions provided by the vendors or available licensed copies of the products. On one of the products multiple resource constrained scheduling calculations were performed with different sort or prioritization criteria. This was conducted to further evaluate the effect of different prioritization criteria on the resource constrained scheduling results.

All of the responses and the various scheduling results were checked to ensure that the baseline network had been entered properly and that the scheduling procedures did not violate the dependencies of the sample project. The detailed analysis of the individual results is included in the next section. A

list of vendors contacted and considered valid is attached as Appendix H. The actual responses to all of the surveys are to large to include in this thesis. Instead, a summary of the responses is included as Appendix I. In addition, the original responses and background research for this thesis are available from the supervising professor via the University of Texas at Austin.

5. ANALYSIS OF DATA

5.1 Time Constrained Resource Scheduling Procedure

In order to analyze the effectiveness of each software's time constrained scheduling procedures, the evaluation metric was calculated for each vendor's software product For each product the daily resource requirement from the time constrained solution was entered into a computer spreadsheet. The spreadsheet was then used to calculate the square of the change in resource requirements from one day to the next. Finally, the squares of the changes in resource requirements was summed over the duration of the project. The resultant is considered an excellent metric of the effectiveness of the product's time constrained resource scheduling procedure when compared to the same metric calculated for the baseline schedule of the same network.

The time constrained resource scheduling metric for these responses ranged from a low of 115 to a high of 249. The value of 115 equals the value obtained by the manual time constrained scheduling solution. A value of 249 is equal to the value obtained for the project baseline and is indicative of no change in the project schedule when the time constrained resource scheduling procedures were conducted. Figures 1 and 2 compare the daily resource requirements that were calculated by each product for the time constrained

resource scheduling solution. Only one product, that labeled as "Product B" in figure 1, equaled the manual solution's effectiveness as demonstrated by the metric value of 115. Products A, C, F, and M all obtained values of 165 for the evaluation metric. Product E obtained a metric value of 177. Products D, J and L obtained metric values of 249 indicating that there was no effective change from the baseline schedule.

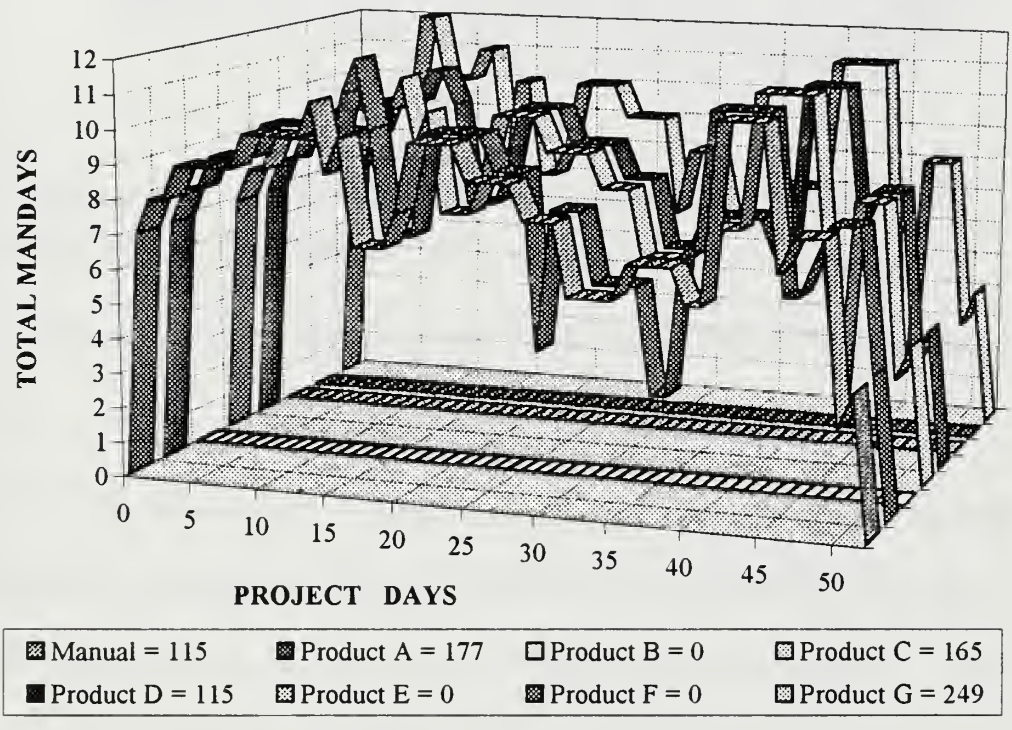


Figure 1: Time Constrained Resource Scheduling Results

Part I (Products A through G)

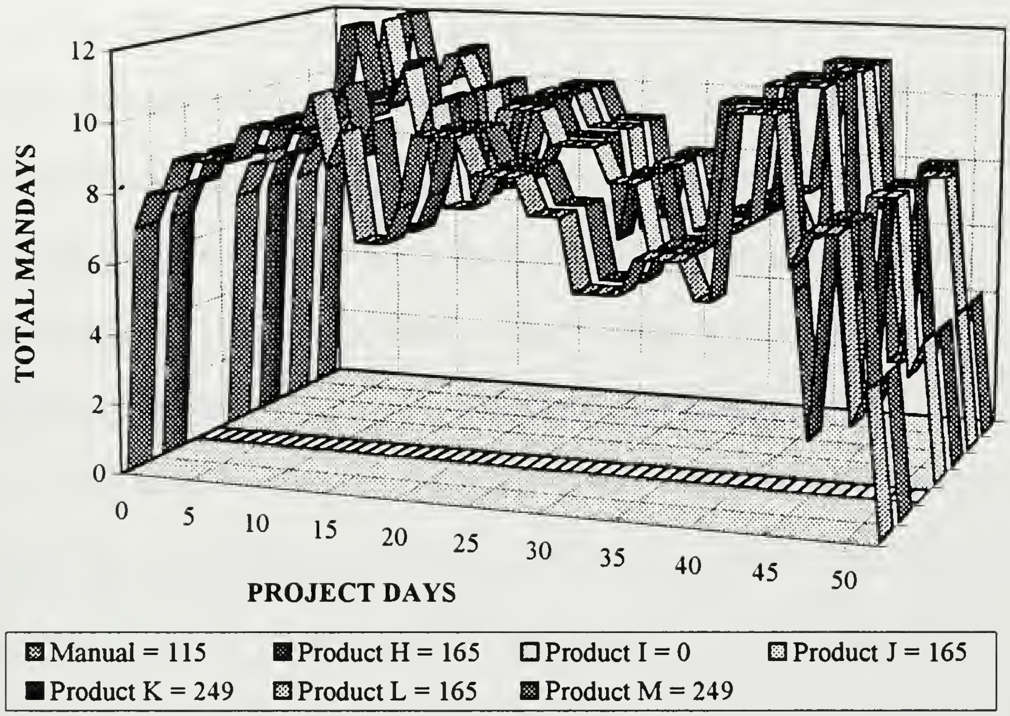


Figure 2: Time Constrained Resource Scheduling Results

Part II (Products H through M)

The fact that any two products obtained the same metric does not mean that the two resulting schedules are identical. This can best be demonstrated by a detailed comparison of the manual solution and that for product B. Both obtained the same metric but there are differences in the two schedules. For example, on project day 9 the manual solution schedules activities 50 and 20 to start. Product B on the other hand delays activity 20 an additional day even

though sufficient resources are available. The additional delay neither violates the project dependencies nor delays to the early completion of the project. Product B's solution is perfectly acceptable with in the rules of time constrained resource scheduling. Without the ability to analyze the actual calculation algorithms for product B it is not possible to determine the exact difference in the calculation procedures. Similar differences can be found between the products which obtained an effectiveness metric of 165.

The range of values for the time constrained scheduling metric was much wider than expected, and can be attributed to two factors. First, the square function of the metric itself was chosen intentionally to exaggerate any minor differences in the effectiveness of the various scheduling procedures. The second factor is attributable only to the effectiveness of the time constrained scheduling procedures used by the different software programs. The results clearly indicate that all of the programs do not provide the best solution, or in some cases, any improvement over the baseline schedule.

5.2 Resource Constrained Resource Scheduling Procedure

The analysis of the results from the resource constrained solutions was not as straight forward as expected. Although a relatively simple metric was

used to quantify the differences in performance, the causes of the differences was difficult to detect. The metric used for comparison was the percent of overall delay in the completion of the project. For each response, the original project baseline duration of 51 project days was subtracted from the total project duration after the resource constrained scheduling procedures were performed. This difference in durations was divided by the original duration and multiplied by 100 to achieve a percent delay for the project. For example, the calculation of the metric for the manual solution to resource constrained scheduling was: (56 - 51) / 51 x 100 = 9.8% delay in early completion of the project.

The values of the percent delay metric for the various solutions ranged from a low of 3.9% to a high of 31.37%. Five of the solutions matched the manual solution's performance of a 9.8 % delay in early completion of the project. Only one software product, identified as product G, improved on the manual solution with a percent delay of 3.9% or only two project days. Initially, the reason for this improved performance was not readily apparent as the tabular report of the resource constrained scheduling results only showed the original early start and early finish dates. However, when the resource histogram of the scheduling results was analyzed on a day by day basis it became apparent that the product had split activities. That is that certain

activities were temporarily stopped and then restarted at a later date when resource conflicts arose. For example, on project day fourteen the only way to have a resource total of nine is to split activity 110 and delay the last day of the activity from project day 14 to project day 15. Similarly, on project day 15 the only way to have a total resource requirement of 6 mandays is to delay the last two days of activity 80. Analysis of the results for project days 41 through 47 indicates that activities 210 and 230 were alternately scheduled for one day at a time to avoid the baseline schedule total resource requirement of eleven mandays. This is a classic example of the splitting of activities to minimize daily total resource requirements. Unfortunately, the results for product G can not be compared directly with the results from the other products since activity splits were performed. Figure 3 is the resource histogram of the resource constrained scheduling solution calculate by product G.

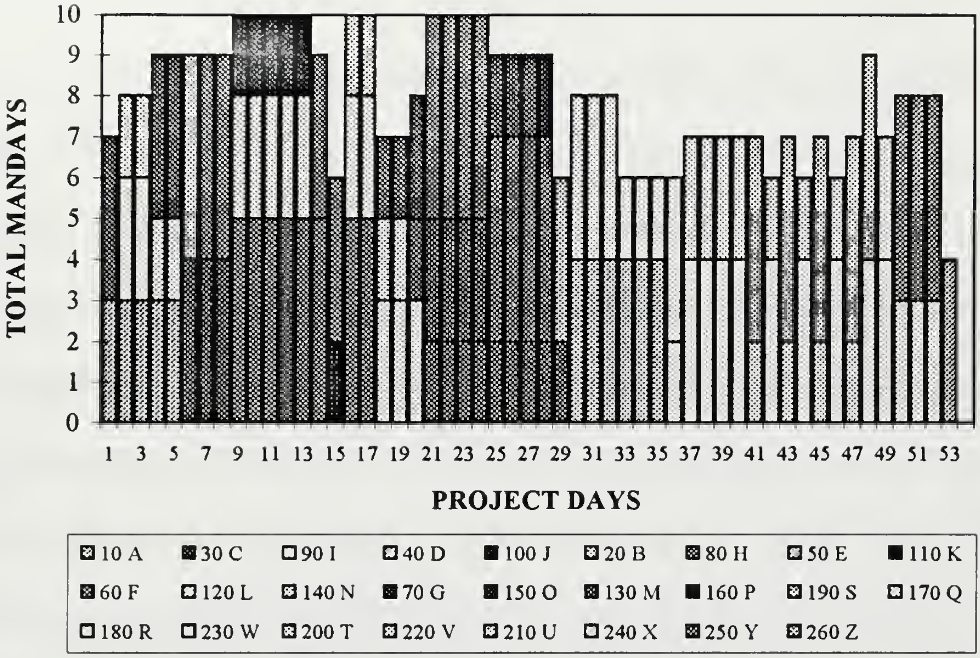


Figure 3: Resource Constrained Histogram for Product G

The resource constrained solution for product A proved even more difficult to analyze. The tabular report of the results for product A shows that activities were not scheduled to occur on full days. Instead, activities were scheduled in tenths of a project day. For example, activity 50 is scheduled to start on day 7.7 and concluded on day 12.7. Therefore, only 3/10 of the three mandays required for activity 50, or .9 total mandays are actually scheduled for project day 8. This causes the resource histogram of the results of the calculations to reflect tenths of a manday required per day. No activity durations were changed and activities were not split. Another complicating

factor is that the product uses day zero as the first project day as opposed to day one. This does not materially affect the results but made comparison to other products more difficult. Two different project durations were used to compare the results to other products. The first project duration (identified as A1) was taken from the resource histogram which showed a total duration of 60 project days. This equates to a performance metric of 17.65% delay in the early completion of the project. The second duration was taken from the Gantt chart provided and which indicates a duration of 59 days or 15.69% delay. For comparison the resource histogram was constructed from the Gantt chart by totaling daily resource requirements per activity. The resource histogram thus developed exceeds the maximum daily resource availability of ten mandays on project days 16 and 46.

The availability of a licensed copy of product J allowed for a further type of analysis for this one product. Product J incorporates a feature which allows the user to specify the sort order or precedence used when performing resource constrained scheduling. This feature was used to demonstrate the affect of different sort orders on the results of the resource constrained scheduling procedures. Five different sort orders were used in performing the resource constrained scheduling and the results identified as products J1, J2, J3, J4, and J5. The sort orders used were: J1, early start, free float, and total

float; J2, early start, early finish, and total float; J3, early finish; J4, late finish; and J5, no sort specified. The five sort orders resulted in five different project durations ranging from 56 to 67 project days. The performance metrics calculated were J1 = 9.8%, J2 = 13.73%, J3 = 17.65%, J4 = 27.45%, and J5 = 31.37%. The five separate resource requirement curves for product J are combined in figure 4.

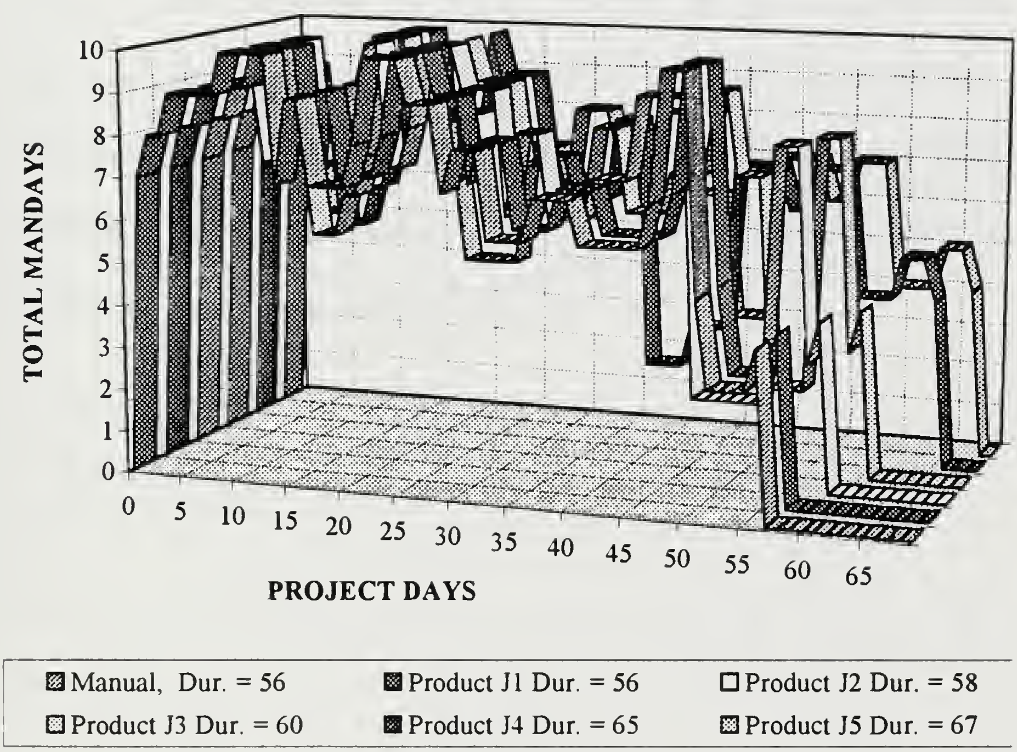


Figure 4: Resource Requirement Curves for Products J1 - J5

In conclusion it should be noted that like the time constrained results, the various schedules for the resource constrained results are not necessarily identical for the various products even though their performance metrics are the same. The reason for this is also very similar to the reasons for the differences in the time constrained results. During the resource constrained scheduling process an activity can potentially have various possible start dates without exceeding the limit on total available resources, violating the establish predecessor to successor relationships, or causing additional delay in the early finish of the project. This can cause minor variations in the way a particular software product schedules an activity with in the rules of resource constrained scheduling. Figures 5 and 6 show the various resource requirement curves for the resource constrained scheduling solutions.

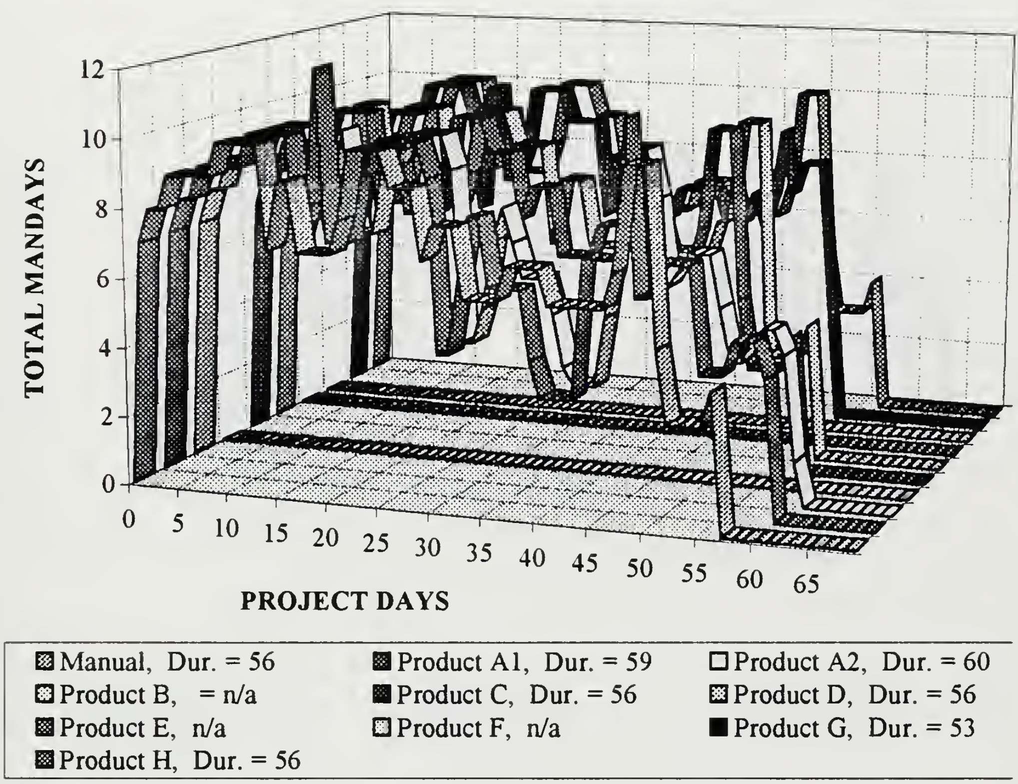


Figure 5: Resource Constrained Resource Scheduling Results

Part I (Products A through H)

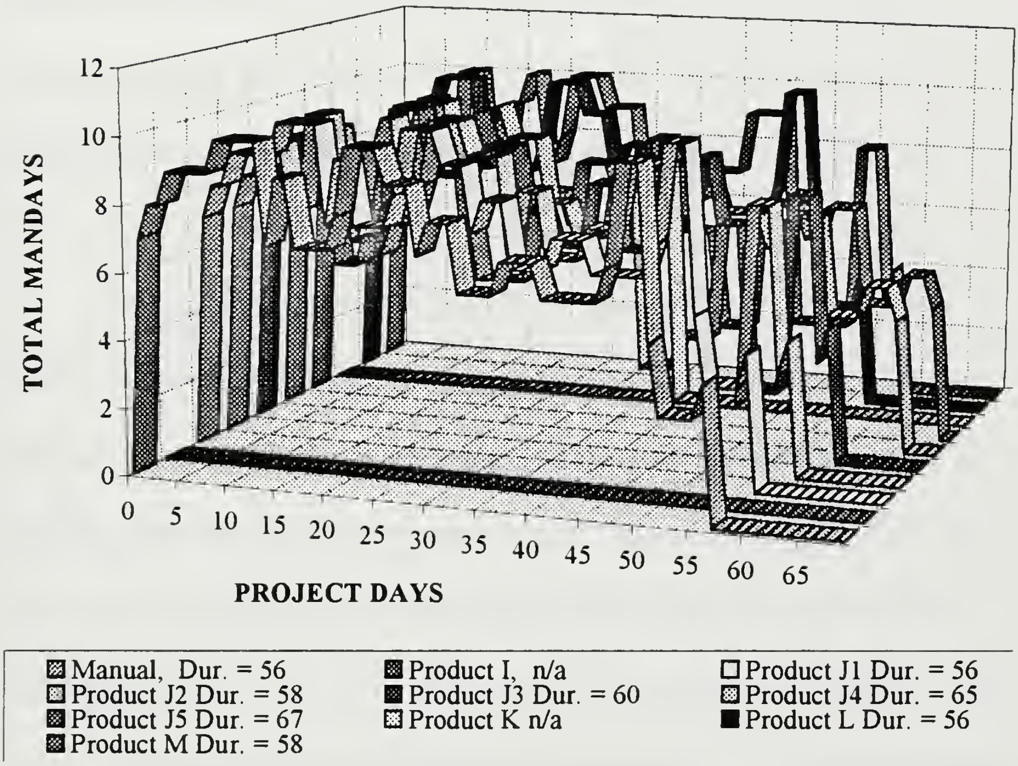


Figure 6: Resource Constrained Resource Scheduling Results

Part II (Products I through M)

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The use of desktop computers in the construction industry has unquestionably been of significant benefit. This is not only true for the personnel in the home office, but for field personnel as well. The use of scheduling software as a planning tool can preclude significant delays in the field.

The research presented in this thesis, however, does point out that there can be significant drawbacks associated with the use of scheduling software. First, the rapid rate of change in the software industry presents a significant problem to users and purchasers of software products. The existence of a software product does not guarantee that the vendor will be available to provide support for the product in even the very near future. This was directly supported by the early phases of research for this thesis when a the of vendors was validated in order to send out the product survey.

The second major drawback with scheduling software is that the effectiveness of the time constrained resource scheduling procedure provided as part of many products is only marginally effective at best. Only one of the products surveyed was able to equal the effectiveness of the optimal solution

developed manually. Project managers should be aware that the product they are using, or considering, may not in fact provide the best possible time constrained resource scheduling solution. Particular attention should be given to the procedures and priorities used in performing the time constrained resource scheduling. Specifically, the user of a particular software product needs to investigate the method which the product uses to decide which activity will be scheduled first when a significant change in total resource requirements occurs.

What has been said for time constrained resource scheduling procedures is also true for resource constrained resource scheduling procedures. Only five of the products surveyed actually obtained the shortest possible schedule given a fixed resource availability. The one exception to this was the product which allowed the splitting of activities. The ability to split activity durations can reduce the delay caused by the resource constrained scheduling of a project. However, splitting should be available as an option which can be selected only if desired by the user or project manager. For resource constrained scheduling the user should investigate the sort criteria or prioritization used in scheduling activities when a resource conflict occurs. This was demonstrated by the multiple scheduling calculations conduct with one software product using different sorting criteria. Particular care should be

taken by the user or project manager when selecting the sort criteria when the software product allows it to be modified. Finally, considering the daily cost of any delay in a project, the time and effort expended in evaluating a software product prior to purchase is very well spent.

6.2 Recommendations for Future Research

The research presented in this thesis made every effort to identify as many scheduling software products as possible. However, the history of the computer and software industry indicates that the list of vendors will only be valid for two to three years. Any future research in the area of scheduling software products will require the identification and revalidation of a new list of vendors and products.

This thesis was also limited to only one sample network. As was discussed earlier, the results from this one project are not transferable to another project. The potential exists for a much broader study. Specifically, a larger number of sample networks should be run through the time and or resource constrained resource scheduling procedures of each software product. The sample networks should vary in the number of activities and over all length. In addition, the assignment of multiple resources per activity would

more closely simulate the reality of project management. Results from the scheduling of a variety of projects using the same software could then be averaged as an improved indicator of the software's over all performance.

APPENDICES

A: **Sample Survey**

Project Management Scheduling Software Survey

Please complete a separate survey for each Project Management Scheduling software product which is currently available from your company. Your time and effort in completing this survey is sincerely appreciated.

Part I: Questionnaire

Company Name:	______________________
Address:	Dept ______________________
	Street ______________________
	City: ______ State: ______ ZIP: ______
Contact:	______________________
Title:	______________________
Telephone:	( ) -
FAX:	( ) -
Product Name:	______________________
Version:	______

System Requirements:	(Mark minimum requirements)
CPU:	☐ 286 ☐ 386 ☐ 486 ☐ Pentium Other: ______
RAM:	☐ 1M ☐ 4M ☐ 8M ☐ 16M Other: ______
Disk Space:	______ Kbytes
Operating System:	☐ DOS ☐ WIN ☐ OS/2 ☐ UNIX Other: ____
Mouse:	☐ Yes ☐ No ☐ Recommended
Other:	______________________
	______________________

Software Features: (Mark features)

GUI: ☐ Yes ☐ No

Multiple users: ☐ Yes ☐ No (multiple users can access the same file)

Multiple file users: ☐ Yes ☐ No (users can access same file simultaneously)

Element control: ☐ Yes ☐ No (access control of data elements)

On-line help: ☐ Yes ☐ No

On-line tutorial: ☐ Yes ☐ No

Software Output: (Given hardware is available)

Type: ☐ Printer ☐ Plotter ☐ Disk file Other: ____

Format: ☐ Tabular reports

☐ Histograms (resource, cost, etc.; periodic or cumulative)

☐ Time scaled activity bar charts

☐ Activity on Arrow diagrams (plots using arrow diag. method)

☐ Activity on Node diagrams (plots using critical path method)

Time Analysis:

Number of Activities: __________ (maximum per project)

Number of Calendars: __________ (maximum per project)

Activity Relationship: ☐ Start-Start ☐ Start-Finish ☐ Finish-Start ☐ Finish-Finish

Activity Duration's: ☐Fixed ☐ Resource driven ☐ Effort Driven

Critical Path Analysis: ☐ (performs forward, backward, and float calculations)

Resource Characteristics:

Types of Resources: ☐ Homogeneous (groups or pools of similar resources)

☐ Heterogeneous (individual people/resources can be IDed)

☐ Groups or Teams (individual resources can be grouped)

Max. # of Resources: __________ (absolute max. number of resources per project)

Resource Availability: ☐ Variable availability (avail. can be modified per time period)

☐ Calendars (resources can be available on different schedules)

☐ Multiple cost levels (resources can be assigned normal and premium cost levels)

Resource Scheduling:

- ☐ Performs resource leveling. (Activity start is adjusted within available float to minimize variances in required resource levels without affecting milestones)
- ☐ Performs resource allocation. (Activity start is adjusted to avoid exceeding maximum available resource limits)

Part II: Sample Network

Please enter the sample network below into your software product. The required resource level is constant for the duration of the activity. All relationships are Finish to Start.

Activity ID	Duration	Predecessors	Successors	Resource Level
10	5	None	20	3 Men/Day (MD)
20	1	10, 30	50, 80	5 MD
30	1	None	20, 40, 90	4 MD
40	4	30	60	2 MD
50	5	20	60	3 MD
60	2	40, 50	70, 140	4 MD
70	12	60, 80	170	2 MD
80	10	20	70	5 MD
90	2	30	100	3 MD
100	5	90	110	4 MD
110	6	100	120, 140	2 MD
120	5	110	130	3 MD
130	8	120	190	5 MD
140	4	60, 110	150	2 MD
150	5	140	160, 170	3 MD
160	4	150	180,190	2 MD
170	3	70, 150	180	4 MD
180	4	160, 170	200	2 MD
190	7	130, 160	200, 230	4 MD
200	4	180, 190	210, 220	3 MD
210	5	200	240	5 MD
220	7	200	240, 250	2 MD
230	10	190	250	4 MD
240	4	210, 220	260	3 MD
250	3	220, 230	260	5 MD
260	1	240, 250	None	4 MD

1. After inputting the network **but before performing any leveling or allocation of resources** please produce a tabular report listing at least the Activity ID, Early Start Date, and Early Finish Date.

2. With unlimited resources and with out delaying the Early Finish Date of activity 260, please execute a leveling (smoothing) run/calculation with your software. Please produce the same report as above as well as a daily resource histogram if possible.

3. Finally, limit the total available men/day to ten (10). Please perform an allocation run/calculation and produce the same reports as above.

B: Bar Chart of Sample Project by Early

Bar Chart of Sample Project by Early Start (Part I)

Act. ID	Desc.	Dur.	Men/ Day	Early Start	Late Start	Early Fin.	Late Fin.	Float Tot.	Float Free	Project Day 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	C	1	4	1	2	2	3	1	0	4																													
10	A	5	3	1	1	6	6	0	0	3	3	3	3	3																									
90	I	2	3	2	3	4	5	1	0		3	3																											
40	D	4	2	2	10	6	14	8	6		2	2	2	2																									
100	J	5	4	4	5	9	10	1	0				4	4	4	4	4																						
20	B	1	5	6	6	7	7	0	0						5																								
50	E	5	3	7	9	12	14	2	0							3	3	3	3	3																			
80	H	10	5	7	7	17	17	0	0							5	5	5	5	5	5	5	5	5	5														
110	K	6	2	9	10	15	16	1	0									2	2	2	2	2	2																
60	F	2	4	12	14	14	16	2	1												4	4																	
140	N	4	2	15	16	19	20	1	0															2	2	2	2												
120	L	5	3	15	16	20	21	1	0															3	3	3	3	3											
70	G	12	2	17	17	29	29	0	0																	2	2	2	2	2	2	2	2	2	2	2	2		
150	O	5	3	19	20	24	25	1	0																			3	3	3	3	3							
130	M	8	5	20	21	28	29	1	0																				5	5	5	5	5	5	5	5			
160	P	4	2	24	25	28	29	1	0																								2	2	2	2			
190	S	7	4	28	29	35	36	1	0																												4	4	4
170	Q	3	4	29	29	32	32	0	0																													4	4
180	R	4	2	32	32	36	36	0	0																														
230	W	10	4	35	38	45	48	3	2																														
200	T	4	3	36	36	40	40	0	0																														
210	U	5	5	40	42	45	47	2	2																														
220	V	7	2	40	40	47	47	0	0																														
250	Y	3	5	47	48	50	51	1	1																														
240	X	4	3	47	47	51	51	0	0																														
260	Z	1	4	51	51	52	52	0	0																														
DAILY TOTAL MANDAYS =										7	8	8	9	9	9	12	12	10	10	10	11	11	7	10	10	7	7	8	10	10	10	10	9	9	9	9	6	8	8
SMOOTHNESS = 249										1	0	1	0	0	9	0	4	0	0	1	0	16	9	0	9	0	1	4	0	0	0	1	0	0	0	9	4	0	0

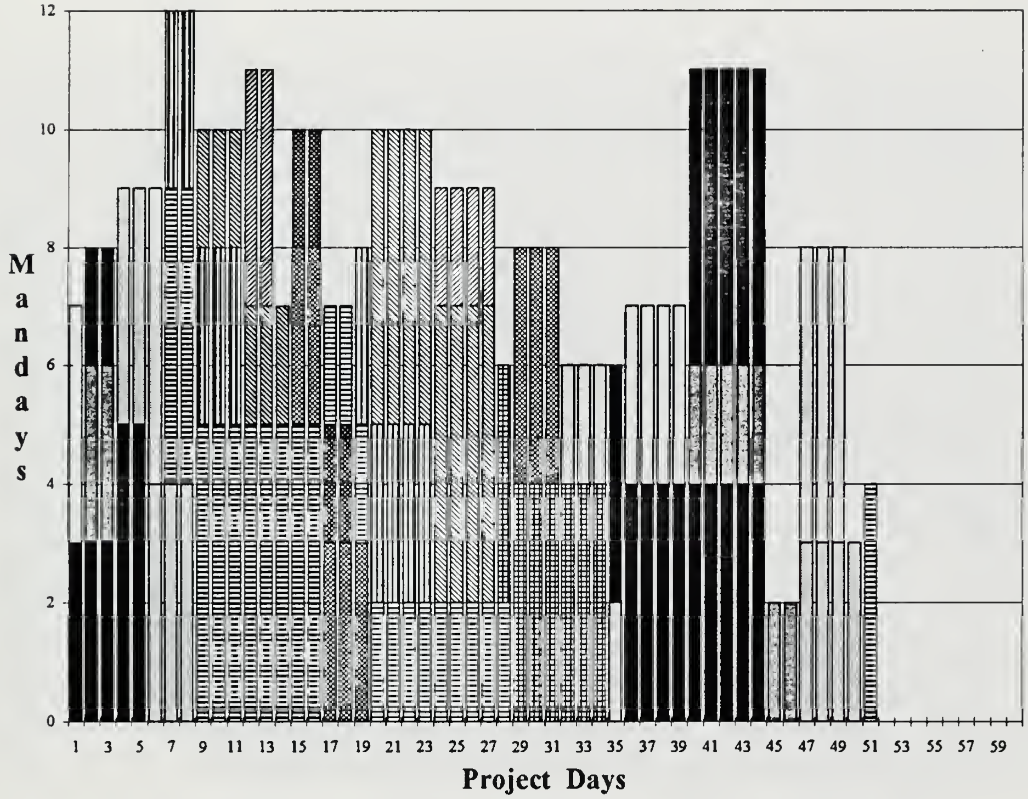
- Mandays Required; - Total Float; - Free Float; - Delays; - Critical Activities

Bar Chart of Sample Project by Early Start (Part II)

Act.			Men/	Early	Late	Early	Late	Float		Project Day																													
ID	Desc.	Dur.	Day	Start	Start	Fin.	Fin.	Tot.	Free	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
30	C	1	4	1	2	2	3	1	0																														
10	A	5	3	1	1	6	6	0	0																														
90	I	2	3	2	3	4	5	1	0																														
40	D	4	2	2	10	6	14	8	6																														
100	J	5	4	4	5	9	10	1	0																														
20	B	1	5	6	6	7	7	0	0																														
50	E	5	3	7	9	12	14	2	0																														
80	H	10	5	7	7	17	17	0	0																														
110	K	6	2	9	10	15	16	1	0																														
60	F	2	4	12	14	14	16	2	1																														
140	N	4	2	15	16	19	20	1	0																														
120	L	5	3	15	16	20	21	1	0																														
70	G	12	2	17	17	29	29	0	0																														
150	O	5	3	19	20	24	25	1	0																														
130	M	8	5	20	21	28	29	1	0																														
160	P	4	2	24	25	28	29	1	0																														
190	S	7	4	28	29	35	36	1	0	4	4	4	4																										
170	Q	3	4	29	29	32	32	0	0	4																													
180	R	4	2	32	32	36	36	0	0		2	2	2	2																									
230	W	10	4	35	38	45	48	3	2					4	4	4	4	4	4	4	4	4	4																
200	T	4	3	36	36	40	40	0	0						3	3	3	3																					
210	U	5	5	40	42	45	47	2	2										5	5	5	5	5																
220	V	7	2	40	40	47	47	0	0										2	2	2	2	2	2	2														
250	Y	3	5	47	48	50	51	1	1																	5	5	5											
240	X	4	3	47	47	51	51	0	0																	3	3	3	3										
260	Z	1	4	51	51	52	52	0	0																					4									
DAILY TOTAL MANDAYS =										8	6	6	6	6	7	7	7	7	11	11	11	11	11	2	2	8	8	8	3	4	0	0	0	0	0	0	0	0	0
										4	0	0	0	1	0	0	0	16	0	0	0	0	81	0	36	0	0	25	1	16	0	0	0	0	0	0	0	0	0

- Mandays required   - Total Float   - Free Float   - Delays   - Critical Activities

C: Resource Histogram of Sample Project by Early



D: Bar Chart of Sample Network After Manual Time Constrained Resource Scheduling

Bar Chart of Sample Network After Manual Time Constrained Resource Scheduling (Part I)

Act. ID	Desc.	Dur.	Men/ Day	Early Start	Late Start	Early Fin.	Late Fin.	Float Total	Free	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	C	1	4	1	2	2	3	1	0	4																													
10	A	5	3	1	1	6	6	0	0	3	3	3	3	3																									
90	I	2	3	2	3	4	5	1	0		3	3																											
40	D	4	2	2	10	6	14	8	8		2	2	2	2																									
100	J	5	4	4	5	9	10	1	0				4	4	4	4	4																						
20	B	1	5	6	6	7	7	0	0						5																								
50	E	5	3	11	13	12	14	0	0									3	3	3	3	3																	
80	H	10	5	7	7	17	17	0	0							5	5	5	5	5	5	5	5	5	5														
110	K	6	2	9	10	15	16	1	0									2	2	2	2	2	2																
60	F	2	4	14	14	16	16	0	0														4	4															
140	N	4	2	16	16	20	20	0	0																2	2	2	2											
120	L	5	3	16	16	21	21	0	0																3	3	3	3	3										
70	G	12	2	17	17	29	29	0	0																	2	2	2	2	2	2	2	2	2	2	2	2		
150	O	5	3	20	20	25	25	0	0																				3	3	3	3	3						
130	M	8	5	21	21	29	29	0	0																					5	5	5	5	5	5	5	5		
160	P	4	2	25	25	29	29	0	0																									2	2	2	2		
190	S	7	4	29	29	36	36	0	0																													4	4
170	Q	3	4	29	29	32	32	0	0																													4	4
180	R	4	2	32	32	36	36	0	0																														
230	W	10	4	36	36	46	48	2	1																														
200	T	4	3	36	36	40	40	0	0																														
210	U	5	5	42	42	47	47	0	0																														
220	V	7	2	40	40	47	47	0	0																														
250	Y	3	5	47	48	50	51	1	1																														
240	X	4	3	47	47	51	51	0	0																														
260	Z	1	4	51	51	52	52	0	0																														
DAILY TOTAL MANDAYS =										7	8	8	9	9	9	9	9	10	10	10	10	10	11	9	10	7	7	7	8	10	10	10	10	9	9	9	9	8	8
SMOOTHNESS = 115										1	0	1	0	0	0	0	1	0	0	0	0	1	4	1	9	0	0	1	4	0	0	0	1	0	0	0	1	0	0

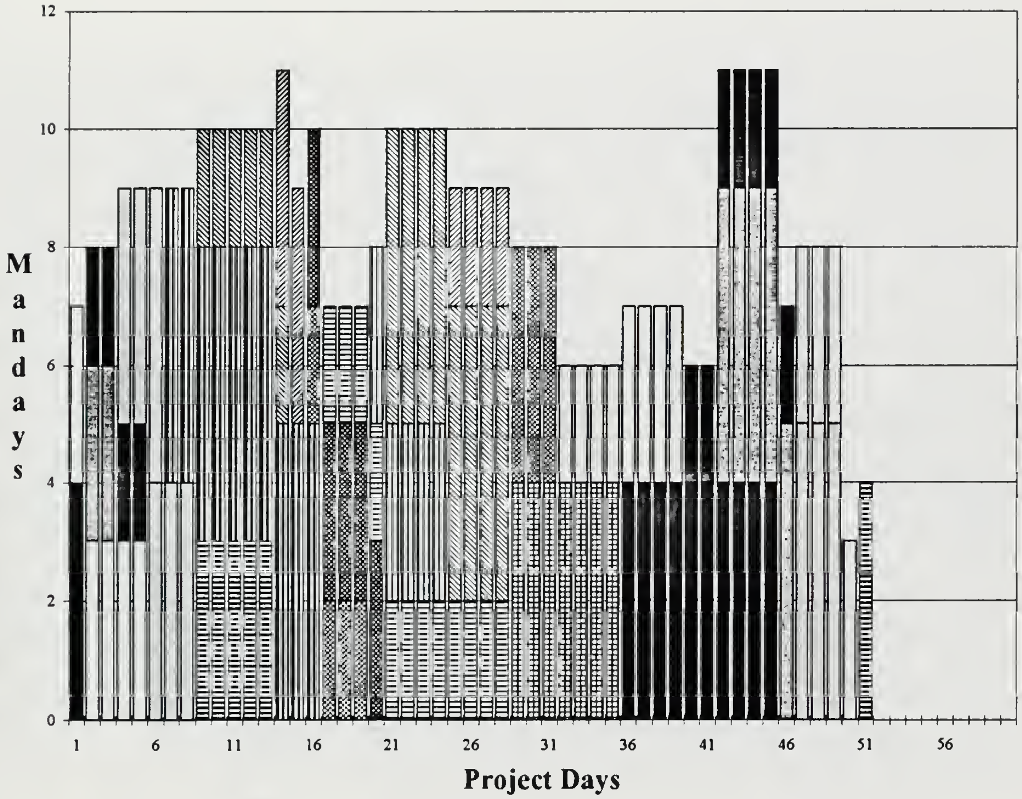
= Mandays Required; = Total Float; = Free Float; = Delays; = Critical Activities

Bar Chart of Sample Network After Manual Time Constrained Resource Scheduling (Part II)

Act.			Men/	Early	Late	Early	Late	Float		Project Day																													
ID	Desc.	Dur.	Day	Start	Start	Fin.	Fin.	Total	Free	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
30	C	1	4	1	2	2	3	1	0																														
10	A	5	3	1	1	6	6	0	0																														
90	I	2	3	2	3	4	5	1	0																														
40	D	4	2	2	10	6	14	8	8																														
100	J	5	4	4	5	9	10	1	0																														
20	B	1	5	6	6	7	7	0	0																														
50	E	5	3	11	13	12	14	0	0																														
80	H	10	5	7	7	17	17	0	0																														
110	K	6	2	9	10	15	16	1	0																														
60	F	2	4	14	14	16	16	0	0																														
140	N	4	2	16	16	20	20	0	0																														
120	L	5	3	16	16	21	21	0	0																														
70	G	12	2	17	17	29	29	0	0																														
150	O	5	3	20	20	25	25	0	0																														
130	M	8	5	21	21	29	29	0	0																														
160	P	4	2	25	25	29	29	0	0																														
190	S	7	4	29	29	36	36	0	0	4	4	4	4	4																									
170	Q	3	4	29	29	32	32	0	0	4																													
180	R	4	2	32	32	36	36	0	0		2	2	2	2																									
230	W	10	4	36	36	46	48	2	1						4	4	4	4	4	4	4	4	4	4															
200	T	4	3	36	36	40	40	0	0						3	3	3	3																					
210	U	5	5	42	42	47	47	0	0												5	5	5	5	5														
220	V	7	2	40	40	47	47	0	0										2	2	2	2	2	2	2														
250	Y	3	5	47	48	50	51	1	1																	5	5	5											
240	X	4	3	47	47	51	51	0	0																	3	3	3	3										
260	Z	1	4	51	51	52	52	0	0																					4									
DAILY TOTAL MANDAYS =										8	6	6	6	6	7	7	7	7	6	6	11	11	11	11	7	8	8	8	3	4	0	0	0	0	0	0	0	0	0
										4	0	0	0	1	0	0	0	1	0	25	0	0	0	16	1	0	0	25	1	16	0	0	0	0	0	0	0	0	0

\# = Mandays required | = Total Float | = Free Float | = Delays | = Critical Activities

E: Resource Histogram After Manual Time Constrained Resource Scheduling



F: Bar Chart of Sample Network After Manual Resource Constrained Resource Scheduling

Bar Chart of Sample Network After Manual Resource Constrained Resource Scheduling (Part I

Act.			Men/	Early	Late	Early	Late	Float		Project Days																													
ID	Desc.	Dur.	Day	Start	Start	Fin.	Fin.	Total	Free	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
30	C	1	4	1	1	2	2	0	0	4																													
10	A	5	3	1	4	6	9	3	0	3	3	3	3	3																									
90	I	2	3	2	2	4	4	0	0		3	3																											
40	D	4	2	2	5	6	9	3	0		2	2	2	2																									
100	J	5	4	4	4	9	9	0	0				4	4	4	4	4																						
20	B	1	5	6	8	7	9	3	0						5																								
50	E	5	3	9	10	14	15	1	1									3	3	3	3	3																	
80	H	10	5	7	11	17	21	4	0							5	5	5	5	5	5	5	5	5	5														
110	K	6	2	9	9	15	15	0	0									2	2	2	2	2	2																
60	F	2	4	15	15	17	17	0	0															4	4														
140	N	4	2	17	17	21	21	0	0																	2	2	2	2										
120	L	5	3	17	17	22	22	0	0																	3	3	3	3	3									
70	G	12	2	17	21	29	34	4	0																	2	2	2	2	2	2	2	2	2	2	2	2		
150	O	5	3	21	21	26	26	0	0																					3	3	3	3	3					
130	M	8	5	22	22	30	30	0	0																						5	5	5	5	5	5	5	5	
160	P	4	2	26	26	30	30	0	0																										2	2	2	2	
190	S	7	4	30	30	37	37	0	0																														4
170	Q	3	4	30	34	33	37	4	0																														4
180	R	4	2	33	37	37	41	4	0																														
230	W	10	4	37	37	47	47	0	0																														
200	T	4	3	37	41	41	45	4	0																														
210	U	5	5	47	47	52	52	0	0																														
220	V	7	2	41	45	48	52	4	0																														
250	Y	3	5	48	53	51	56	5	5																														
240	X	4	3	52	52	56	56	0	0																														
260	Z	1	4	56	56	57	57	0	0																														
DAILY TOTAL MANDAYS =										7	8	8	9	9	9	9	9	10	10	10	10	10	7	9	9	7	7	7	7	8	10	10	10	10	9	9	9	7	8
SMOOTHNESS =									101	1	0	1	0	0	0	0	1	0	0	0	0	9	4	0	4	0	0	0	1	4	0	0	0	1	0	0	4	1	0

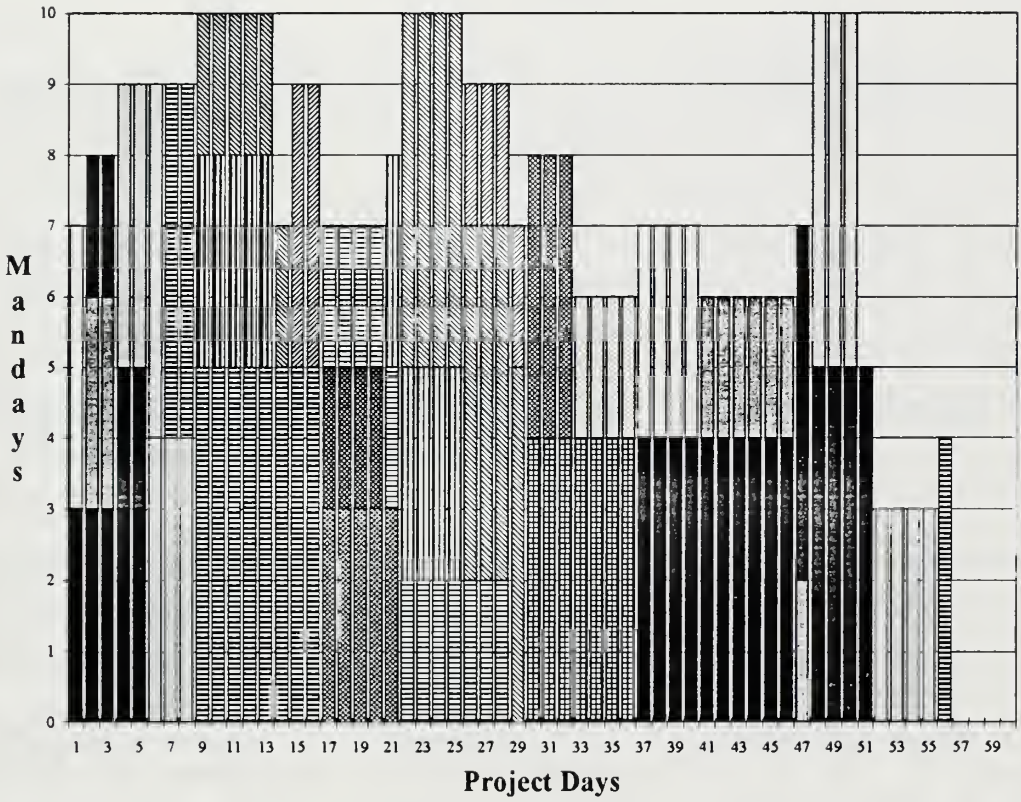
= Mandays Required — Total Float — Free Float — Delays — Critical Activities

Bar Chart of Sample Network After Manual Resource Constrained Resource Scheduling (Part II)

Act. ID	Desc.	Dur.	Men/ Day	Early Start	Late Start	Early Fin.	Late Fin.	Float Total	Float Free	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
30	C	1	4	1	1	2	2	0	0																														
10	A	5	3	1	4	6	9	3	0																														
90	I	2	3	2	2	4	4	0	0																														
40	D	4	2	2	5	6	9	3	0																														
100	J	5	4	4	4	9	9	0	0																														
20	B	1	5	6	8	7	9	3	0																														
50	E	5	3	9	10	14	15	1	1																														
80	H	10	5	7	11	17	21	4	0																														
110	K	6	2	9	9	15	15	0	0																														
60	F	2	4	15	15	17	17	0	0																														
140	N	4	2	17	17	21	21	0	0																														
120	L	5	3	17	17	22	22	0	0																														
70	G	12	2	17	21	29	34	4	0																														
150	O	5	3	21	21	26	26	0	0																														
130	M	8	5	22	22	30	30	0	0																														
160	P	4	2	26	26	30	30	0	0																														
190	S	7	4	30	30	37	37	0	0	4	4	4	4	4	4																								
170	Q	3	4	30	34	33	37	4	0	4	4																												
180	R	4	2	33	37	37	41	4	0			2	2	2	2																								
230	W	10	4	37	37	47	47	0	0							4	4	4	4	4	4	4	4	4	4														
200	T	4	3	37	41	41	45	4	0							3	3	3	3																				
210	U	5	5	47	47	52	52	0	0																	5	5	5	5	5									
220	V	7	2	41	45	48	52	4	0											2	2	2	2	2	2	2													
250	Y	3	5	48	53	51	56	5	5																		5	5	5										
240	X	4	3	52	52	56	56	0	0																						3	3	3	3					
260	Z	1	4	56	56	57	57	0	0																										4				
DAILY TOTAL MANDAYS										8	8	6	6	6	6	7	7	7	7	6	6	6	6	6	6	7	10	10	10	5	3	3	3	3	4	0	0	0	0
										0	4	0	0	0	1	0	0	0	1	0	0	0	0	0	1	9	0	0	25	4	0	0	0	9	16	0	0	0	0

- Mandays required; - Total Float; - Free Float; - Delays; - Critical Activities

G: Resource Histogram After Manual Resource Constrained Resource Scheduling



H: List of Vendors

Address	Point of Contact		Product
AccuraTech Inc.	Ray Sauer		*Timetable 5.0*
5422 Chevy Chase Dr.	Phone:	(713) 960-9385	
Houston, TX 77056	FAX:	(713) 960-9313	
AGS Management Systems, Inc.	Barry O'Conner		*firstcase*
1060 First Avenue, Suite 400	Phone:	(610) 265-1550	
King of Prussia, PA 19406	FAX:	(610) 265-1230	
AlderGraf Systems, Inc.	Leon Alderfer		*Aldergraf Scheduling System 5.2*
10620 Stebbins Circle, Suite R	Phone:	(713) 467-8500	
Houston, TX 77043	FAX:	(713) 467-1062	
American Contractor	Leslye Love		*American Contractor*
933 Larkin Valley Rd.	Phone:	(800) 333-8435	
Watsonville, CA 95076	FAX:	(408) 724-5391	
Applied Business Technology Corporatio	Bernie Cassidy		*Project Workbench for Windows*
361 Broadway	Phone:	(212) 219-8945	
New York, NY 10013	FAX:	(212) 219-3597	
Armor Systems, Inc.	Victoria Keller		*Advantage Series*
1626 W. Airport Blvd.	Phone:	(407) 323-9787	
Sanford, FL 32773	FAX:	(407) 330-0442	
ASA Andrew Sipos Associates	Andrew Sipos		*Project Scheduling Library PRO*
P.O. Box 3397 Church Street Station	Phone:	(212) 321-2408	
New York, NY 10008	FAX:	(212) 321-2408	
Cambridge Management Systems, Inc.	Mark Almasin		*SSP'S PROMIS*
50 Redfield Street, Suite 206	Phone:	(919) 881-0988	
Boston, MA 02122	FAX:	(617) 661-0758	

Address	Point of Contact		Product
Christensen Computer Co	Alan Christensen		*AlphaLEDGER*
12005 N. Panorama Dr. Ste. 204	Phone:	(602) 837-7173	
Fountain Hills, AZ 85268	FAX:		
Computer Associates International, Inc.	Dan Streib		*CA - SuperProject for Windows*
One Computer Associates Plaza	Phone:	(404) 916-3850	
Islandia, NY 11788	FAX:	(404) 916-3880	
ComputerLine, Inc.	Jerry Richardi		*OUTLOOK*
6219 Executive Blvd.	Phone:	(301) 231-8727	
Rockville, MD 20852	FAX:	(301) 231-0825	
CONAC Software	Tom D'Sena		*CONAC 1000*
4590 MacArthur Blvd., Suite 550	Phone:	(800) 326-7575	
Newport Beach, CA 92660	FAX:	(604) 273-3092	
Construction Data Services, Inc	Keith Gill		*Construction Management System*
4989 Santa Anita Ave.	Phone:	(818) 401-0039	
Temple City, CA 91780	FAX:		
Constructive Computing	Blaine Camp		*QuickEST*
5800 Inland Dr.	Phone:	(913) 596-2113	
Kansas City, KS 66106	FAX:		
Dekker, Ltd.	Debra Walters		*Dekker Tracker 3.0*
636 E. Breir Drive, Suite 260	Phone:	(909) 384-9000	
San Bernadino, CA 92408	FAX:	(909) 889-9163	
Design Consultants, Inc.	Mark Feinstein		*STARpro*
500 Northwest Plaza, Suite 514	Phone:	(314) 770-0616	
St. Louis, MO 63074	FAX:	(314) 434-9350	
Dexter & Chaney	Mark Dexter		*Forefront CMS*
3200 N.E. 125th St.	Phone:	(206) 364-1400	
Seattle, WA 98125	FAX:		

Address	Point of Contact		Product
Digital Tools	Paul Work		*Auto PLAN II*
10351 Bubb Road	Phone:	(408) 366-6920	
Cupertino, CA 95014	FAX:	(408) 446-2140	
DLW Infosystems	David Webber		*DLWcpm*
P.O. Box 850778	Phone:	(214) 690-1954	
Richardson, TX 75085	FAX:		
Elite Software Development, Inc.			*CPM/PERT*
P.O. Box 1194	Phone:	(409) 846-2340	
Bryan, TX 77806	FAX:		
Ferril Company	Jana		*Total Construction Management Sy*
	Phone:	(800) 328-8267	
Denver, CO 80303	FAX:	(303) 234-5645	
Galaxy Advanced Engineering, Inc.	Bahman Zohuri		*VISION/Project Management Softw*
1165 Chess Dr., Suite A	Phone:	(415) 525-1314	
Foster City, CA 94010	FAX:	(415) 525-0406	
IMSI	Cathleen Montanos		*Viewpoint*
1895 East Francisco	Phone:	(415) 454-7101	
San Rafael, CA 94901	FAX:	(415) 257-8466	
InfoSource Corp.	Jeff Sweeney		*Construction Management Software*
3220 Riverside Dr.	Phone:	(800) 442-2402	
Columbus, OH 43221	FAX:	(614) 487-1259	
Integrated Software Services	Bob Sculley		*Time Machine*
4370 Tujunga Avenue, Suite 130	Phone:	(800) 333-1979	
Studio City, CA 91604	FAX:	(818) 506-0949	
Lucas Management Systems	Chip Kylng		*Artemis Prestige*
5333 Westhimer, Suite 700	Phone:	(713) 626-1511	
Houston, TX 77056	FAX:	(713) 626-1004	

Address	Point of Contact		Product
Mantix Systems	Tom Isaac		*CASCADE*
12020 Sunrise Valley Drive, Suite 120	Phone:	(703) 715-2450	
Reston, VA 22091	FAX:	(703) 715-2456	
Maxwell Systems, Inc.	Joann Cooperryder		*CONTRACTOR*
2838 Dekalb Pike	Phone:	(800) 688-8226	
Norristown, PA 19401	FAX:	(610) 277-2081	
Micro Planning International, Inc.	Sally Berg		*X-Pert Ver 2.3*
3801 E. Florida Avenue, Suite 507	Phone:	(303) 757-2216	
Denver, CO 80210	FAX:	(303) 757-2047	
Microsoft Corporation	Jennifer Coffi		*Microsoft Project*
One Microsoft Way	Phone:	(206) 882-8080	
Redmond, WA 98052	FAX:	(206) 936-7329	
Monitor Systems, Inc.	Al Ruiz		*TaskMonitor*
960 N. San Antonio Road, Suite 210	Phone:	(415) 949-1688	
Los Altos, CA 94022	FAX:	(415) 949-4688	
National Info. Systems	Arden Scott		*Action Graphic Vue*
1190 Saratoga Ave.	Phone:	(408) 985-7100	
San Jose, CA 95129	FAX:	(408) 246-3127	
Pinnell/Busch, Inc.	Perry Smith		*PMS80*
6420 S.W. Macadam Ave., Suite 330	Phone:	(503) 293-6280	
Portland, OR 97201	FAX:	(503) 293-6284	
PlanView, Inc.	Julie Fowler		*PlanView 2.10*
7320 N. MOPAC, Suite 312	Phone:	(512) 346-8600	
Austin, TX 78731	FAX:	(512) 346-9180	
Primavera Systems, Inc.	Nicole Stephano		*Primavera Project Planner for Wind*
Two Bala Plaza	Phone:	(610) 667-8600	
Bala Cynwyd, PA 19004	FAX:	(610) 660-5857	

Address	Point of Contact	Product
Primavera, Sure Trak Division	Dave Broschinsky	*Sure Trak*
1574 W. 1700 South	Phone: (801) 973-1330	
Salt Lake City, UT 84104	FAX: (801) 973-0953	
Pro-Mation, Inc.	Mark Jensen	*Contractor' Edge*
1145 East South Union Ave.	Phone: (801) 261-8595	
Midvale, UT 84047	FAX: (801) 261-8599	
Project Software & Development, Inc. (P	Russell Phillips	*PROJECT/2*
20 University Road	Phone: (800) 366-7734	
Cambridge, MA 02138	FAX: (313) 271-8937	
Protelisis	Karen Bovien	*Enterprise PM*
429 Santa Monica Blvd., Suite 460	Phone: (310) 393-4552	
Santa Monica, CA 90401	FAX: (310) 451-2888	
Research Engineers, Inc.	John Putnam	*AutoPROJECT*
22700 Savi Ranch Parkway	Phone: (714) 974-2500	
Yorba Linda, CA 92687	FAX: (714) 974-4771	
Robbins-Gioia, Inc.	Lou Jobin	*CAT II*
209 Madison Street	Phone: (703) 548-7006	
Alexandria, VA 22314	FAX: (703) 739-6129	
SAS Institute, Inc.	Renee Samy	*SAS System*
SAS Campus Dr.	Phone: (919) 677-8000	
Cary, NC 27513	FAX: (919) 677-8123	
Scitor Corporation	Mike Rosenbaum	*Project Scheduler*
393 Vintage Park Drive, Suite 140	Phone: (800) 533-9876	
Foster City, CA 94404	FAX: (415) 570-7807	
Small System Design, Inc.	Wendy Krause	*CMS*
2540 Frontier Ave., Suite 104	Phone: (800) 272-0053	
Boulder, CO 80301	FAX: (303) 442-7881	

Address	Point of Contact	Product
Symantec Corporation	Christy Jennings	*Timeline 6.0 for Windows*
7200 Redwood Boulevard, Suite 300	Phone: (415) 899-8258	
Novato, CA 94945	FAX: (415) 898-1297	
TimePhaser Corporation	Bob Crinsley	*TimePhaser GWS*
4141 Jutland Drive, #201	Phone: (619) 685-4436	
San Diego, CA 92117	FAX:	
Universal Construction Software, Inc.	Gregory Kirk	*Power Tools*
120 S. R. 419	Phone: (407) 327-3020	
Winter Springs, FL 32708	FAX:	
Welcom Software Technology	Tony Welch	*TEXIM Project*
15995 N. Barker's Landing, Suite 275	Phone: (713) 558-0514	
Houston, TX 77079	FAX: (713) 584-7828	
Work Management Solutions, Inc.	Jeff Szarka	*MULTITRAK / Planview*
119 Beach Street	Phone: (617) 482-6677	
Boston, MA 02111	FAX: (617) 482-6233	
XPM Partners, Inc	Jim Suszka	*XPM*
23010 Lake Forest Drive, #321	Phone: (714) 707-4720	
Laguna Hills, CA 92653	FAX: (714) 707-4514	

I: Summary of Vendor Responses

AccuraTech Inc. **Timetable 5.0**

System Requirements: CPU: **286** RAM: **1** Disk: **1000** OS: **DOS, UN**
Mouse: **No** OtherSR:

Software Features: GUI: **No** MultiUser: **No** MultiFile: **No** ElemControl: **No**
Help: **Yes** Tutor: **No**

Software Output: Print: **Yes** Plot: **No** Disk: **Yes** Other: **Arrow & Node avail with**
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **No**

Time Analysis: # of Act: **Unlim** # of Calen: **96** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **No** Effort Driven: **No**

Resource Characteristics: Max # of Res: **500** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **No** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **No**
Performs Leveling: **Yes** Performs Allocation: **Yes**

AlderGraf Systems, Inc. **Aldergraf Scheduling System**

System Requirements: CPU: **286** RAM: **1** Disk: **20000** OS: **DOS**
Mouse: **No** OtherSR:

Software Features: GUI: **No** MultiUser: **No** MultiFile: **No** ElemControl: **No**
Help: **No** Tutor: **No**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **32000** # of Calen: **50** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **No** Effort Driven: **No**

Resource Characteristics: Max # of Res: **Unlim** Homogeneous: **Yes** Heterogeneous: **No**
Groups: **No** Variable Avail.: **No** Res. Calenders: **No** Mult. Cost Levels: **No**
Performs Leveling: **No** Performs Allocation: **No**

Armor Systems, Inc. **Advantage Series**

System Requirements: CPU: **386** RAM: **1** Disk: **??** OS: **DOS,WI**
Mouse: **Yes** OtherSR:

Software Features: GUI: **No** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **Yes**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **No** Disk: **Yes** Other:
Reports: **Yes** Histogram: **No** Bar: **No** Arrow: **No** Node: **No**

Time Analysis: # of Act: **Unlim** # of Calen: **Unlim** Critical Path Anal.: **No**
SS: **No** SF: **Yes** FS: **No** FF: **No**
Duration Fixed: **No** Resource Driven: **Yes** Effort Driven: **No**

Resource Characteristics: Max # of Res: **Unlim** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **No** Mult. Cost Levels: **No**
Performs Leveling: **No** Performs Allocation: **Yes**

ASA Andrew Sipos Associates **Project Scheduling Library P**

System Requirements: CPU: **286** RAM: **1** Disk: **2000** OS: **DOS**
Mouse: **No** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **Yes**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **No** Disk: **Yes** Other:
Reports: **Yes** Histogram: **No** Bar: **No** Arrow: **No** Node: **No**

Time Analysis: # of Act: **29000** # of Calen: **10** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **No**

Resource Characteristics: Max # of Res: **99000** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Computer Associates Internation **CA - SuperProject for Windo**

System Requirements: CPU: **386** RAM: **4M** Disk: **10M** OS: **WIN**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **No** ElemControl: **No**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **Yes**

Time Analysis: # of Act: **16,000** # of Calen: **Unlim** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **No** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **??** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Dekker, Ltd. **Dekker Tracker 3.0**

System Requirements: CPU: **486** RAM: **32** Disk: **??** OS: **DOS, WI**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **Yes**
Help: **Yes** Tutor: **No**

Software Output: Print: **Yes** Plot: **No** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **Unlim** # of Calen: **10** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **Unlim** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Galaxy Advanced Engineering, I **VISION/Project Management**

System Requirements: CPU: RAM: Disk: OS:
Mouse: **No** OtherSR:

Software Features: GUI: **No** MultiUser: **No** MultiFile: **No** ElemControl: **No**
Help: **No** Tutor: **No**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **40000** # of Calen: **4** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Micro Planning International, In **X-Pert Ver 2.3**

System Requirements: CPU: **386** RAM: **4M** Disk: **4,900** OS: **WIN,UNI**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **No** ElemControl: **No**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **15,000** # of Calen: **500** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **No**

Resource Characteristics: Max # of Res: **500** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Microsoft Corporation **Microsoft Project**

System Requirements: CPU: **286** RAM: **2** Disk: **3,600** OS: **WIN**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **No**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other: **Files compatible with Mac**
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **9,999** # of Calen: **9,999** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **9,999** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

PlanView, Inc. **PlanView 2.10**

System Requirements: CPU: **386** RAM: **4** Disk: **500** OS: **WIN, OS**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **Yes**
Help: **Yes** Tutor: **No**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **No**

Time Analysis: # of Act: **Unlim** # of Calen: **Unlim** Critical Path Anal.: **Yes**
SS: **No** SF: **No** FS: **Yes** FF: **No**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **yes** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Primavera Systems, Inc. **Primavera Project Planner for**

System Requirements: CPU: **486** RAM: **8** Disk: **??** OS: **WIN**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **Yes**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **Yes**

Time Analysis: # of Act: **100,000** # of Calen: **31** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **Unlim** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **No** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Primavera, Sure Trak Division **Sure Trak**

System Requirements: CPU: **386** RAM: **4** Disk: **16,000** OS: **WIlN**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **No** ElemControl: **No**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **Yes**

Time Analysis: # of Act: **Blank** # of Calen: **Blank** Critical Path Anal.: **Yes**
SS: **Yes** SF: **No** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **Blank** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **No**
Performs Leveling: **No** Performs Allocation: **Yes**

Research Engineers, Inc. **AutoPROJECT**

System Requirements: CPU: **486** RAM: **8M** Disk: **5M** OS: **DOS/WI**
Mouse: **Yes** OtherSR: **AutoCAD 12/386**

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **No**
Help: **Yes** Tutor: **No**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **Yes** Node: **Yes**

Time Analysis: # of Act: **100,000** # of Calen: **Unlim** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **100,000** Homogeneous: **Yes** Heterogeneous: **No**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

Symantec Corporation **Timeline 6.0 for Windows**

System Requirements: CPU: **386** RAM: **2** Disk: **2,000** OS: **WIN**
Mouse: **Yes** OtherSR:

Software Features: GUI: **Yes** MultiUser: **Yes** MultiFile: **Yes** ElemControl: **No**
Help: **Yes** Tutor: **Yes**

Software Output: Print: **Yes** Plot: **Yes** Disk: **Yes** Other:
Reports: **Yes** Histogram: **Yes** Bar: **Yes** Arrow: **No** Node: **Yes**

Time Analysis: # of Act: **1,000** # of Calen: **1,000** Critical Path Anal.: **Yes**
SS: **Yes** SF: **Yes** FS: **Yes** FF: **Yes**
Duration Fixed: **Yes** Resource Driven: **Yes** Effort Driven: **Yes**

Resource Characteristics: Max # of Res: **1,000** Homogeneous: **Yes** Heterogeneous: **Yes**
Groups: **Yes** Variable Avail.: **Yes** Res. Calenders: **Yes** Mult. Cost Levels: **Yes**
Performs Leveling: **Yes** Performs Allocation: **Yes**

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VITA

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